Table 4.1
Grain Size Analysis for Jet Probe Samples
Jet Probes Located on or Near the Centerline of the Proposed Channel

Sample	Approx. Depth ft NGVD	Mean (mm) M_{mm}	Mean (phi) M_{phi}	Sorting S_{phi}	Variance S^2_{phi}	% Silt <230 sieve	% > 2 mm	%> 1 mm	Type of Analysis
			BIJP-02-01						
Top	-4.9	0.20	2.30	0.58	0.34	1.52	0.15	0.43	Sieve
Middle	-11.9	.18 to .25	--	--		--			Visual
Bottom	-18.9	.20 to .25	--	--		--			Visual
			BIJP-02-03						
Top	-11.7	.25 to .35	--	--		--			Visual
Middle	-18.4	.23 to .30	--	--		--			Visual
Bottom	-25.2	0.25	2.00	0.74	0.55	1.71	0.19	0.94	Sieve
			BIJP-02-05						
Top	-4.3	.23 to .27	--	--		--			Visual
Middle	-13.8	0.25	1.99	0.89	0.79	1.27	0.35	1.94	Sieve
Bottom	-23.3	.23 to .27	--	--		--			Visual
			BIJP-02-07						
Top	-3.4	0.20	2.32	0.45	0.20	1.52	0.20	0.50	Sieve
Middle	-13.4	.18 to .23	--	--		--			Visual
Bottom	-23.4	.20 to .25	--	--		--			Visual
			BIJP-02-08						
Top	-12.3	0.29	1.77	0.95	0.90	1.38	1.55	4.10	Sieve
Middle	-19.0	.30 to .40	--	--		--			Visual
Bottom	-25.8	.30 to .40	--	--		--			Visual
			BIJP-02-09						
Top	-4.5	.18 to .23	--	--		--			Visual
Middle	-12.5	0.26	1.92	0.72	0.52	1.34	0.46	1.51	Sieve
Bottom	-20.5	.20 to .25	--	--		--			Visual
			BIJP-02-11						
Top	-2.8	0.30	1.74	0.66	0.44	1.03	0.32	1.33	Sieve
Middle	-8.8	.25 to .30	--	--		--			Visual
Bottom	-14.8	.33 to .35	--	--		--			Visual
			BIJP-02-13						
Top	-3.4	.38 to .42	--	--		--			Visual
Middle	-10.4	0.35	1.52	1.10	1.21	1.53	2.64	6.97	Sieve
Bottom	-17.4	.38 to .42	--	--		--			Visual
			BIJP-02-14						
Top	-4.4	.25 to .30	--	--		--			Visual
Middle	-11.4	.20 to .25	--	--		--			Visual
Bottom	-18.4	0.30	1.75	0.78	0.61	1.39	0.93	2.75	Sieve
			BIJP-02-15						
Top	-5.4	0.36	1.49	0.65	0.42	1.14	0.06	1.01	Sieve
Middle	-13.9	.30 to .35	--	--		--			Visual
Bottom	-22.4	.33 to .38	--	--		--			Visual
			BIJP-02-16						
Top	-6.5	0.20	2.35	0.49	0.24	1.78	0.01	0.17	Sieve
Middle	-14.2	.17 to .23	--	--		--			Visual
Bottom	-22.0	.17 to .23	--	--		--			Visual
			BIJP-02-17						
Top	-5.5	.20 to .25	--	--		--			Visual
Middle	-13.5	.25 to .30	--	--		--			Visual
Bottom	-21.5	0.33	1.59	0.68	0.46	1.52	0.31	0.31	Sieve
			BIJP-02-18						
Top	-14.7	0.16	2.63	0.49		1.77	0.00	0.08	Sieve
Middle	-24.2	.17 to .23	--	--		--			Visual
Bottom	-33.7	.17 to .23	--	--		--			Visual
			BIJP-02-19						
Top	-11.4	0.36	1.48	0.90	0.81	1.93	0.65	4.27	Sieve
Middle	-19.9	.40 to .45	--	--		--			Visual
Bottom	-28.4	.30 to .35	--	--		--			Visual
Ave all Sieve Samp		**0.27**	**1.92**	**0.76**	**0.58**	**1.49**	**0.56**	**1.88**	

Table 4.2
Summary of Grain Size Analysis of Vibracore Samples

Number	Approx. Depth ft NGVD	Mean (mm) M_{mm}	Mean (phi) M_{phi}	Sorting S_{phi}	Variance S^2_{phi}	% Silt <230 sieve	% > 2 mm	%> 1 mm
BIVC-02-01								
BIVC-02-01 #1	-3.8	0.26	1.94	0.86	0.74	1.20	1.36	3.05
BIVC-02-01 #2	-4.8	0.21	2.24	0.51	0.26	1.59	0.03	0.00
BIVC-02-01 #3	-8.8	0.24	2.04	0.82	0.67	1.62	1.27	2.94
BIVC-02-01A #1	-11.1	0.64	0.63	2.32	5.38	0.91	18.96	26.33
BIVC-02-01B #1	-20.5	0.64	0.64	1.56	2.43	0.57	11.30	27.27
BIVC-02-02								
BIVC-02-02 #1	-5.0	0.28	1.83	0.88	0.77	1.19	1.38	3.97
BIVC-02-02 #2	-7.3	0.24	2.08	0.56	0.31	1.33	0.21	0.41
BIVC-02-02 #3	-9.0	0.37	1.43	1.22	1.49	1.21	4.33	8.72
BIVC-02-02 #4	-12.0	0.25	2.02	0.55	0.30	1.24	0.00	0.12
BIVC-02-03								
BIVC-02-03 #1	-5.3	0.34	1.56	0.88	0.77	1.03	1.18	3.81
BIVC-02-03 #2	-8.8	0.31	1.69	0.98	0.96	1.36	1.98	5.18
BIVC-02-03 #3	-10.8	1.34	-0.43	2.22	4.93	0.73	30.24	48.99
BIVC-02-03 #4	-12.3	0.45	1.16	0.93	0.86	0.80	3.18	7.32
BIVC-02-03A #1	-13.5	0.21	2.27	0.49	0.24	1.59	0.54	0.68
BIVC-02-04								
BIVC-02-04 #1	-14.3	0.26	1.94	0.84	0.71	1.21	0.48	1.73
BIVC-02-04 #2	-16.3	0.38	1.41	1.52	2.31	1.28	5.26	13.20
BIVC-02-04A #1	-17.5	0.27	1.91	0.90	0.81	1.11	0.00	1.09
BIVC-02-04A #2	-19.2	0.52	0.93	1.64	2.69	0.96	10.32	19.69
BIVC-02-04B #1	-20.7	0.87	0.19	2.12	4.49	0.93	21.97	33.59
BIVC-02-05								
BIVC-02-05 #1	-24.8	0.15	2.74	0.57	0.32	1.88	0.18	0.55
BIVC-02-05 #2	-28.1	0.65	0.61	1.55	2.40	1.20	10.11	19.38
Average all samples		**0.42**	**1.47**	**1.27**	**1.61**	**1.19**	**5.92**	**10.86**
Average of samples above -17.5		0.38	1.61	**1.16**	1.35	1.21	4.40	7.97

4.5. The results of the jet probe and vibracore investigations indicate fairly uniform sand deposits throughout the proposed channel corridor with minor layers of shell fragments and shell hash and minimal amounts of silt. No layers of clay were observed in any of the vibracores. In terms of silt content, both the jet probe samples and the vibracore samples had generally less than 2 percent silt (i.e., grain sizes less than 0.0625 mm). This is somewhat surprising since jet probes generally result in the fine-grained material going into suspension once it reaches the surface. One interpretation could be that there is basically very little silt in the ebb tide delta. With respect to the coarser fraction of the material, the vibracores indicated higher concentrations of sediment with grain sizes larger than 1 mm or 2 mm compared to the jet probe data. For the Bogue Inlet/Bogue Banks area, grain sizes equal to or greater than 1 mm are generally composed of shells (King 2002). The average amount of vibracore material with grain sizes equal to or greater than 2 mm was approximately 6% compared to only 0.6% for the jet probe samples. Material equal to or larger than 1 mm averaged almost 11% for the vibracore samples compared to only 2% for the jet probe samples. The higher concentration of coarse grain material in the vibracore samples was mostly found at depths greater than –17.5 feet NGVD. If only the samples obtained from depths equal to or less than –17.5 feet NGVD are used to determine the percent of coarse-grained material in the vibracore samples, the amount of material equal to or greater than 2 mm is about 4.5% while the percent greater than 1 mm is about 8%. These percentages are still somewhat larger than those found in the jet probe samples. The difference in the concentration of coarse-grained material is obviously due to the sampling method. While jet probes are known to result in the dispersion of silt and clay, in this case, they must also have not transported the coarser fraction of the sediment to the surface.

4.6. Given the apparent bias in the jet probe samples, only the vibracore samples were used to compute weighted composite grain size distributions for 3 channel depths; namely, -13.5 feet NGVD, -15.5 feet NGVD, and -17.5 feet NGVD. These three channel depths cover the range of likely channel depths that could be recommended for the relocated channel. The computational procedure used to determine the composite grain size characteristics are provided in Appendix B. The results of the composite distributions for the three channel depths are summarized in Table 4.3.

Table 4.3
Computed Composite Distributions - 2002 Bogue Inlet Vibracores
For Channel Depths of -13.5-ft, -15.5-ft, and 17.5-ft NGVD

Depth of Cut Feet below NGVD	Phi (M_Φ)	Mean (mm) (M_{mm})	Phi Sorting (s_Φ)	Percent Silt $d \leq$ 0.0625mm	Percent $d \geq 2$ mm	Percent $d \geq 1$ mm
-13.5	1.72	.30	1.05	1.25	4.97	8.58
-15.5	1.76	.30	0.98	1.25	4.65	8.09
-17.5	1.67	.31	1.14	1.24	4.40	7.97

4.7. In July 2002, Sarah King of the University of North Carolina at Chapel Hill Institute for Marine Science (King 2002), collected foreshore samples (toe of dune seaward to –1 meter depth) from 15 stations along Bogue Banks and analyzed the samples for percent gravel (d>2mm) and percent fines (d<0.0625 mm). Sample stations 3 to 8 where in the area nourished during Phase I of the Bogue Banks beach nourishment project. Also, stations 1 and 2 are located in an area that receives material from maintenance dredging of the Morehead City Harbor navigation project. Her results are plotted on Figure 4.3. For the areas located outside of the nourishment zone, the percent of gravel size material averaged around 2.5% (range from ~1% to ~7%) compared to 13.5% (range from ~4.5% to ~23.0%) in the nourishment zone. She found that 100% of the gravel sized material was carbonate (shell). The percent of fines on the east end of Bogue Banks and in the nourishment zone averaged approximately 1.5% to 2.0% while the west end of the

Emerald Isle shoreline, only had around 0.2% fines. For the most part, the percent of gravels and fines in Bogue Inlet compare favorably with the concentrations found in the unnourished portions of Bogue Banks. Even though the percent fines in Bogue Inlet are relatively low, they are still 6 times greater than the concentrations found on the west end of Bogue Banks. If the in place concentrations of fines remained around 1.25% following deposition, this could be a cause for some concern regarding impacts on beach infauna. Normally, however, fines go into suspension once the material leaves the dredge pipe with the fines remaining suspended and transported away from the foreshore. If the Bogue Inlet material is used to nourish the west end of Bogue Banks, the in place concentration of fines following the initial winnowing and sorting process are expected to be less than the in situ concentrations found during the subsurface investigations and closer to the concentrations found by King.

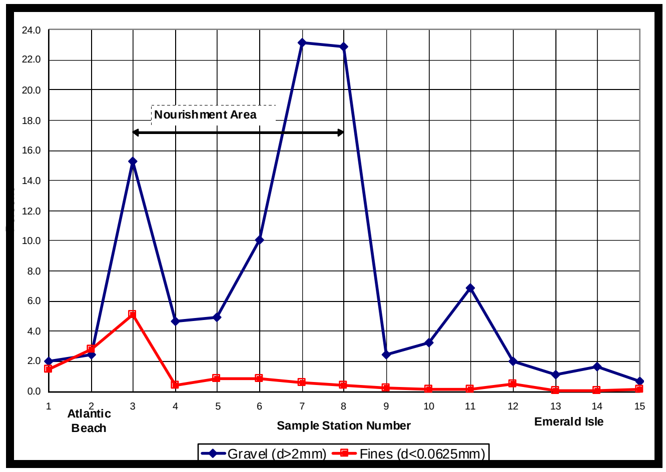

Figure 4.3 Percent of Gravel (d>2mm) and Fines (d<0.062 mm) Foreshore Samples Collected on Bogue Banks S. King – UNC Institute for Marine Science

4.8. A minimal amount of grain size information is available from the CSE vibracores. Mean grain sizes of sediment collected from selective vibracores are indicated next to the core location on Figure 4.2. Generally, CSE found rather coarse mean grain sizes (.55 mm and .30 mm) on the inner margins of the channel (CSE cores C07 and C10 respectively on Figure 4.2) with smaller gain sizes located on the outer portions of the ebb tide delta (CSE cores C01, C02, and C05). The mean grain sizes for C01, C02, and C05 were .27 mm, .40 mm, and .19 mm respectively. The CSE data generally agrees with the information obtained by CPE from the jet probes and 5 vibracores.

4.9. The vibracores obtained by the Corps of Engineers have not been analyzed at this time. Since most of the Corps vibracores are located outside of the proposed channel corridor, they would not have a significant impact on the characterization of the material to be removed during the channel relocation project.

4.10. Characteristics of the Native Beach Material. When beach fill material is placed on the upper portion of the beach, it undergoes a certain degree of sorting by wave action that tends to move discrete grains sizes to quasi-equilibrium positions on the active beach profile. In general, the coarser fraction of the borrow material will remain on the upper or higher energy portion of the profile while the finer grained material will be transported to deeper depths. Accordingly, compatibility analyses between beach fill material and native beach material is normally carried out using composite characteristics that include samples of the native beach out to some depth of closure of the fill with the pre-project profile. Based on the wave climate in the Bogue Banks area and the configuration of the existing beach profile, the depth of closure appears to be approximately 20 feet below MLW (-21.5 feet NGVD). The Corps of Engineers, as part of an island wide Federal storm damage reduction feasibility study, collected samples of the native material for the entire length of the island from the base of the dune seaward to the 24-foot depth contour with samples being collected at 2-foot depth intervals across the profile. Four of the profiles sampled by the Corps of Engineers are located within the area that would be nourished by the material obtained from the Bogue Inlet channel relocation project. The samples collected from these four profiles out to a depth of -20 feet NGVD were used to compute the characteristics of the native beach material within the Phase 3 beach nourishment area. Table 4.4 provides a summary the characteristics of the samples collected at discrete points on the profile and the characteristics of the composite native material for these four profiles.

Table 4.4
Characteristics of the Native Beach Material
Phase 3 – Emerald Isle Beach Nourishment Project
(Corps of Engineers Profile Stations 962+84.91, 1033+59.23, 1103+90.23, 1174+03.3)

Sample Location	Average Shell Content (% by weight)	Mean (mm)	Mean (phi units)	Standard Deviation (phi units)
Berm Crest	2.20	0.24	2.05	0.459
MHW	5.16	0.25	2.0	0.617
MSL	16.44	0.39	1.36	1.085
MLW	27.87	0.48	1.07	1.404
-3	4.87	0.22	2.19	0.611
-4	2.46	0.21	2.25	0.524
-6	1.50	0.18	2.49	0.277
-8	1.38	0.16	2.60	0.258
-10	1.63	0.15	2.70	0.332
-12	2.17	0.16	2.68	0.369
-14	1.61	0.17	2.52	0.442
-16	2.59	0.17	2.52	0.442
-18	2.59	0.16	2.60	0.563
-20	2.70	0.16	2.68	0.369
Composite	**5.37**	**0.22**	**2.26**	**0.790**

4.11. Compatibility Analysis. The compatibility of borrow material for use as beach fill is determined by a numerical method that compares the mean grain size and sorting characteristics of the borrow material to the mean and sorting characteristics of the native beach material. The results of that comparison yields a factor known as the overfill ratio (R_a) which is an indication of the number of cubic yards of borrow material needed to result in 1 cubic yard of sorted beach fill material. If the borrow material is completely compatible with the native material, R_a will be equal to 1.0 and the net volume of material needed will equal the gross or borrow area volume. R_a greater than 1.0 means that more material is needed from the borrow area to yield 1 cubic yard of sorted material on the beach. For the three channel depths given in Table 4.3, the overfill ratios were computed to be 1.015 for the 13.5-foot channel, 1.006 for the 15.5-foot channel, and 1.029 for the 17.5-foot channel. The silt content for each of the three channel depths is around 1.25 percent (98.75% sand). When silt is discharged through the pipe, it immediately goes into suspension and does not contribute to the volume of material on the beach. Therefore, the overfill requirement must be adjusted for the silt content. This is obtained by dividing R_a by the percent of sand in the borrow material. Accordingly, the adjusted overfill factor for each of the three channel depths are 1.03 for the 13.5-foot channel, 1.02 for the 15.5-foot channel, and 1.04 for the 17.5-foot channel.

4.12. The overfill factors for all three channel depths indicate that the Bogue Inlet material is highly compatible with the native beach material with total sorting and winnowing losses expected to be 5 percent or less. This is not particularly surprising as the ebb tide delta is composed primarily of material derived from the adjacent beaches. Apart from the compatibility of the grain sizes, when material is removed from a borrow area and deposited on a beach, there are inherent differences in the volume of material removed from the borrow area compared to the volume that can be measured on the beach. Much of this difference is due to measurement error and a factor commonly referred to as shrinkage. Based on past experience, the difference between borrow area volume and the volume of sediment retained on the beach generally ranges from 10 to 20 percent. Since the material in Bogue Inlet is highly compatible with the native beach material, the total overfill factor used for beach fill quantity estimates is 1.15. For an overfill factor of 1.15, the total or gross volume of material that would be required to satisfy the beach nourishment requirements for Phase 3 of the Emerald Isle beach nourishment project would be 810,000 cubic yards.

5.0 DESIGN OF THE RELOCATED CHANNEL

5.1. Introduction. As discussed earlier, the primary purpose of the channel relocation project is to create a stable channel that will capture the majority of the flow through the inlet and divert flow away from the Pointe area of Emerald Isle. If the dredged channel is too small, frictional forces could prevent velocities in the channel from attaining magnitudes necessary to flush littoral sediment out of the channel resulting in the eventual closure of the new channel. Also, even though the channel may be just large enough to capture the flow, initial adjustments in the channel cross-sectional area immediately following construction could lead to excessive scour with possible deposition of the scoured material in the connecting channels, adjacent marshes, and wetland areas. If the channel is excessively large, it will gradually shoal back to a more stable cross-section, however, during the period of adjustment, the tidal prism of the inlet (i.e., the total volume of water that flows through the inlet during an ebb of flood cycle) could be increased. In addition, the material required to shoal the channel could adversely impact the sediment balance on the adjacent beaches. Accordingly, the design focus was on developing the proper size channel that would be large enough to remain open without an excessive amount of shoaling yet small enough not to cause excessive scour. The design for the relocated channel included consideration of the size characteristics of the existing ebb tide channel, numerical model studies of tides and currents in the inlet, and channel shoaling/stability criteria. An added feature of the overall design of the channel relocation project is the closure of the existing channel by constructing a sand dike in the vicinity of the Pointe. In this regard, the numerical model was also used to evaluate the impacts of closing the existing channel on flow patterns as well as assessing the impacts of the proposed inlet modifications on flow circulation throughout the inlet complex.

5.2. Tidal Prism/Cross-Sectional Area Relationship. O'Brien (1969) discovered a strong relationship between the cross-sectional area of an inlet (measured at mean sea level) and its spring tidal prism, that is the volume of water passing through the inlet during a normal spring tide event. This relationship comes about as a result of the natural balancing of tidal flow forces that tend to scour the inlet and littoral transport that deposits sediment in the inlet. Most of the inlets included in O'Brien's earlier work focused on inlets on the West Coast of the United States. Jarrett (1976) developed refinements in this functional relationship by considering inlets on the Atlantic, Gulf, and West Coast of the U.S. as well as whether the inlets were stabilized with one jetty, two jetties, or not stabilized by structures. The form of this relationship is:

$$A_c=\alpha P^n$$

where:

- A_c = cross-sectional area (square feet) of the inlet below mean sea level measured at the narrowest point between the adjacent island (inlet throat) ;
- α = empirical coefficient;
- P = spring tidal prism (cubic feet) = volume of water passing through the inlet during a spring tide (ebb or flood, which ever is greater);
- n = empirical coefficient.

The values for the empirical coefficients α and n for unjettied or single jettied inlets on the Atlantic Coast were determined by Jarrett to be 5.37×10^{-6} and 1.07 respectively. Thus the relationship between A and P for east coast single jettied and unjettied inlets is:

$$A = 5.37 \times 10^{-6} P^{1.07}$$

Rearranging this relationship, the tidal prism of an inlet can be computed from a known cross-sectional area by the following:

$$P = 8.42 \times 10^{4} A^{0.93}$$

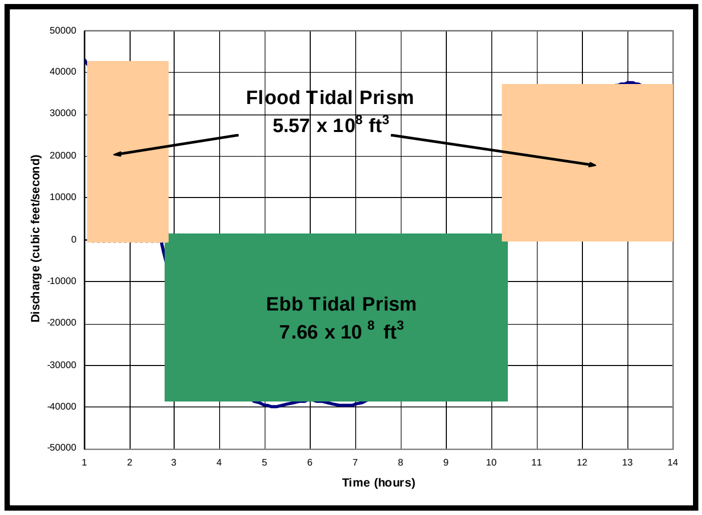

Figure 5.1 Bogue Inlet Tidal Prism 16 October 2001 (CSE 2002)

5.3. Coastal Science and Engineering, PLLC (CSE) measured tidal flows through Bogue inlet on 16 October 2001 during a period of spring tides (CSE January 2002). The results of the CSE flow measurements are plotted on Figure 5.1. As noted on Figure 5.1, ebb tidal prism (P) was 7.66×10^{8} cubic feet while the flood tidal prism was 5.57×10^{8} cubic feet. Substitution of the larger ebb tidal prism in to the above equation yields a predicted equilibrium cross-sectional area for Bogue Inlet of 17,200 square feet. For the flood tidal prism, the equilibrium cross-sectional area would be 12,200 square feet. A reasonable estimate of the equilibrium cross-sectional area of Bogue Inlet would be the average of these two areas or 14,700 square feet. The existing cross-sectional area of Bogue Inlet, obtained from the October 2001 survey conducted by CSE was 13,600 square feet. This existing cross-sectional area is the average for sections 10+00 to 50+00 shown on Figure 5.7, which are located across the throat of the inlet. The agreement between the predicted equilibrium cross-sectional area and the actual cross-sectional area is rather good considering inlets are know to undergo short-term fluctuations in their cross-sectional area of the order of ±10% due to high sediment loads during storms or as a result of changing lunar or meteorological tide conditions. In any event, Bogue Inlet displays a balance between the hydraulic forces tending to keep it open (tidal flow) and sedimentary forces that would tend to close the inlet (littoral transport).

5.4. Design of Channel Cross-Section. The existing ebb channel through the inlet follows a circuitous route (Figure 1.2) from Dudley Island past the Pointe and across the ebb tide delta. The cross-sectional area of the existing ebb channel also varies markedly. Cross-sections of the existing ebb tide channel were measured at 11 points along the channel shown on Figure 5.2 with plots of the 11 cross-sections given on Figures 5.3 to 5.6. These cross-sections were measured from the October 2001 survey of the inlet by Coastal

Science and Engineering PLLC (CSE). Between Stations 1 and 4, the cross-sectional area of the exiting ebb tide channel is relatively small, averaging 6,100 square feet. Between Station 5 and Station 11, the cross-sectional area increases considerably averaging 9,600 square feet. Station 5 is located near the point where the channel bifurcates (Figure 5.2) into a predominant flood channel (east side) and a predominant ebb channel. Maximum depths in the ebb channel vary from around 24 feet below NGVD as the channel passes the Pointe to 8 feet below NGVD as the channel crosses the ebb tide delta. Top widths of the channel also vary over a wide range from a minimum of approximately 600 feet at Station 4 to over 1,500 feet at Station 5.

5.5. As a result of the variable dimensions of the existing channel, the cross-sectional area of the relocated channel will also have a variable cross-section as it projects seaward across the ebb tide delta. The variable cross-section will be accomplished by varying the bottom width of the channel for a given channel depths. Two sets of variable bottom widths were evaluated, one with a maximum width of 400 feet and the other with a maximum width of 500 feet. The variable bottom widths evaluated are as follows:

Stations (feet)	Maximum Bottom Width 400-feet	Maximum Bottom Width 500-feet
0+00 to 25+00	150 feet	150 feet
25+00 to 35+00	Width increased from 150 feet to 400 feet	Width increased from 150 feet to 500 feet
35+00 to 55+00	400 feet	500 feet
55+00 to 60+00	Width decreases from 400 feet to 200 feet	Width decreases from 500 feet to 200 feet
60+00 to End	200 feet	200 feet